भारतीय मानक
Indian Standard

IS 17446 : 2020

चट्टानों में सुरंग बनाने के लिए अवलोकन पद्धति — दिशानिर्देश

Observational Method for Tunnelling in Rock Masses — Guidelines

ICS 093.20

© BIS 2020

भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS
मानक भवन, 9 बहादुरशाह ज़फर मार्ग, नई दिल्ली – 110002
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI-110002
www.bis.gov.in www.standardsbis.in

October 2020 **Price Group 4**

Rock Mechanics Sectional Committee, CED 48

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Rock Mechanics Sectional Committee had been approved by the Civil Engineering Division Council.

In the past, there was little emphasis on instrumentation although adhoc observations were sometimes made if failure appeared imminent. In recent projects, many problems, for example rock bursts, support failures due to intense support pressures generated by squeezing and swelling rocks, water inrush, gas explosion, failure of steel supports, etc, have been observed. The construction engineers are facing these problems while constructing tunnels. As such field instrumentation for support and lining design is gaining popularity among both designers and construction engineers with a little hesitation due to initial hindrance to construction-progress. Of course, eventually construction engineers did realise the net saving in the time of completion of tunnel owing to reduction in number of tunnelling hazards and cost over-runs.

Thus, one of the most important factors in the construction of tunnelling is the observation of tunnel behaviour during construction and accordingly upgrading the design. Monitoring and interpretation of convergence, deformations, strains and stresses and accordingly optimizing working procedures and support requirements are important specially in weaker rock masses.

This is further elaborated with three possible design situations in rock engineering: assessing rock support from rock mass classifications (empirical), assessing local stability in tunnels based on deformation measurements (observational), and assessing the required thickness of shotcrete lining for rock support (analytical). It is important to see that the formal implementation of the observational method in the design of underground excavations should not impose any significant problems to the design process, rather should strengthen the design practices.

The observational method is an accepted alternative to conventional design methods for geotechnical structures. It is an approach for managing uncertainty in tunnel design through heterogeneous rock masses of unknown behaviour. Thus, the observational approach is defined as follows:

a) When prediction of geology along deep tunnels and geotechnical behaviour is difficult, it can be appropriate to apply the observational method, in which the design is reviewed during construction. When this approach is used, the following requirements shall all be made before construction is started:

    1) Scope of monitoring (prediction of uncertain ground properties/behaviour and verification of design assumptions, work control, back analysis, research, risk allocation, assurance and confidence) shall be defined.

    2) Range of all key observation variables requiring monitoring shall be defined in relation to design assumptions and construction sequencing.

    3) Acceptable limits of behaviour shall be established.

    4) Range of possible behaviour shall be assessed and it shall be shown that there is an acceptable probability that the actual behaviour will be within the acceptable limits.

    5) A plan of monitoring shall be devised, which will reveal whether the actual behaviour lies within the acceptable limits. The monitoring shall make this clear at a sufficiently early stage, and with sufficiently short intervals to allow contingency actions to be undertaken successfully.

    6) Response time of the instruments and the procedures for analysing the results shall be sufficiently rapid in relation to the possible evolution of the system.

    7) A plan of contingency actions shall be devised, which may be adopted if the monitoring reveals behaviour outside acceptable limits or rock mass is highly anisotropic or the *in-situ* stresses are highly anisotropic or high to cause rock bursts.

b) During construction, the monitoring shall be carried out as planned and additional or replacement monitoring shall be undertaken if this becomes necessary. The results of the monitoring shall be assessed at appropriate stages and the planned contingency actions shall be put into operation if the limits of behaviour are exceeded. Monitoring equipment shall either be replaced or extended if it fails to supply reliable data of appropriate type or in sufficient quantity.

(*Continued on third cover*)

Indian Standard

OBSERVATIONAL METHOD FOR TUNNELLING IN ROCK MASSES — GUIDELINES

1 SCOPE

1.1 This standard covers the guidelines for monitoring and timely action based on instrumental observations for both small and large underground openings in rock masses.

1.2 Measurements for the *in-situ* stresses have not been dealt in this standard.

1.3 This standard does not cover conventional tunnelling methods in rock masses, which are covered in IS 15026 : 2002 'Guidelines for tunnelling method in rock masses'.

2 BASIC CONSIDERATIONS AND REQUIREMENTS

2.1 Design of an underground structure in rock or evaluation of stability and safety of an existing structure calls for determination of,

a) the deformation and/or stresses in the structure resulting from external loads applied to the structure;
b) the physical properties of the ground in the vicinity of the opening;
c) the ability of the structure to withstand the applied stresses or deformations;
d) the geometry and the sequence of excavation of the opening and supporting of the opening;
e) the regional geology and its influence on the stress and displacement distribution in the vicinity of the opening; and
f) the critical surface developments and nearby underground built environments.

Suitable analytical methods, model studies and/or numerical procedures, such as the finite element or distinct element method are used to incorporate this data into the initial stage of design.

2.2 Expected system behaviour from underground works and probable impact on surroundings should be defined as follows:

a) Allowable deformations in expected influence area of underground construction,
b) Range of deformations anticipated inside tunnels,
c) Range of displacements anticipated over surface (shallow urban environment), and
d) Loads on tunnel lining during construction.

2.3 Functional requirements of monitoring system shall be specified by designer covering,

a) extent of area to be monitored;
b) start and stop criterion of monitoring with its frequency;
c) key variables to be monitored with monitoring density or number of monitoring stations;
d) accuracy and precision of reading required;
e) responsibility of each party;
f) requirements for system verification;
g) data management, storage, processing and interpretation;
h) response requirements (trigger levels) for monitoring; and
j) protection of monitoring equipment.

2.4 Trigger levels connect the monitoring results with response actions. There can be up to three to four trigger levels for comprehensive monitoring programme for critical structures. Typically, each trigger level is assigned a colour coding for easy identification of the condition. Commonly used trigger colour are,

a) *Clear* — Follow the suggested monitoring regime,
b) *Green* — Frequent review of observations,
c) *Amber* — Enhance monitoring regime with frequent review of observations and working methods with alert notification to third parties, and
d) *Red* — Controlled cessation of work, redesign and control access to underground works and check preparedness for emergency.

Trigger levels should be worked out and assigned as per different rock classes and structural requirements.

However, the design (before and during construction) should be frequently evaluated by conducting full scale field tests and then by correlating the field data with predicted results. Repeated feedback of field data into the input data of the design helps in the development of the reliable design techniques. Thus design modifications can be effected if the results of instrumentation and experience warrant. Principles of this procedure are illustrated in Fig. 1.

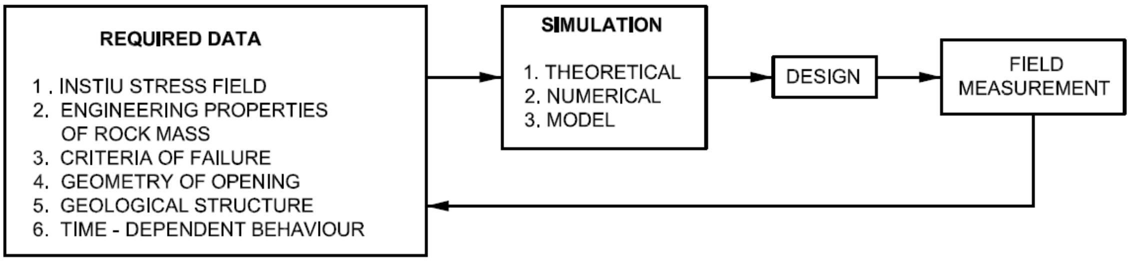

Fig. 1 Basic Requirements for Design of a Structure in Rock

3 DATA REQUIREMENT

3.1 The data obtained from instrumentation work and thus from observation may be used for, (a) selection of economical support during construction period, and (b) determination of basic tunnel lining-design criteria such as in pressure tunnels.

3.2 Following information is required while dealing with tunnel supports in an effective manner,

a) actual *versus* predicted behaviour of unsupported or partially supported openings for verification of assumed ground properties.
b) time for activation of various supports after excavation.
c) medium to long term ground-support interaction patterns.

The answers to these questions can come only through instrumentation, observation and geological data. Thus, zones of high support pressure may be delineated and the pressures are actually measured so that stronger lining is installed but without being over-conservative and taking any risk to life and structure. On the basis of measured loads, it may be possible to use lighter lining compared to that predicted from the design calculations. The actual distribution of load on the lining can also be ascertained.

Stronger lining will be required due to high support pressures which may have resulted due to too early or too late support installations or high variations in tangential stress in surrounding ground due to unfavourable interaction of tunnel shape and earth pressure coefficients.

Another major problem faced by a designer is to know the direction of rock load to be considered in designing a support system, and whether it is absolutely essential to place invert (or bottom strut) along with roof support so that mucking roof operation is least disturbed. The answer is affirmative if measurements on rock load indicate high horizontal support pressure.

It is also important to know the radius of failed rock (called coffin cover or the broken zone) in the cases of squeezing rock masses.

3.3 Table 1 summarizes typical applications of various instruments.

4 ROLE OF INSTRUMENTATION FOR TUNNELLING

Tunnel instrumentation and observation can help in the following ways:

a) Verifying design of support system.
b) Advancing the state-of-the-art.
c) Providing adequacy of new construction techniques.
d) Controlling quality of construction.
e) Reducing construction cost and extra payment.
f) Diagnosing the cause of a problem.
g) Improving construction safety by providing warning system.
h) Documenting as-built conditions.
j) Providing legal protection.
k) Studying the time-dependent behaviour of rock mass.

5 IMPORTANT MEASUREMENT

5.1 Systematic tunnel monitoring by fixing 3-D bireflex targets for tunnel roof and wall displacement/convergence shall always be carried out in the tunnels for better understanding of rock mass-tunnel support interaction. The convergence targets shall be fixed immediately after face excavation at a regular interval of 50 m or as and when required on the basis of the ground condition/geology.

5.2 At one location five bireflex target points (or as per the decision of designer) are fixed to measure tunnel displacement/convergence (*see* Fig. 2). X, Y and Z coordinates of each target point are recorded at regular basis. The readings are analysed on the day of taking readings to get the displacement of individual target point and the chord convergence between various target points. Accordingly, the results are used for countermeasures, if any required.

Table 1 Typical Applications for Various Measuring Instruments

(*Clause* 3.3)

Sl No. (1)	Measurement (2)	Instrument (3)	Typical Applications (4)
i)	Diameter or width change	a) Tape extensometer b) 3-D Bi-reflex targets	Monitoring the roof and wall deformation Monitoring lining distortion
ii)	Surface settlement Monitoring the zone of influence in the rock mass around tunnel periphery	a) 3-D Bi-reflex optical targets b) Single point borehole extensometer with reference datum c) Multi-point borehole extensometer	Forewarning of surface settlement Monitoring the time-dependent deformation within the rock mass around excavated tunnel periphery
iii)	Subsurface horizontal movement	a) Inclinometer b) Borehole extensometer	Forewarning of surface settlement or tunnel instability by monitoring ground movement towards excavation or heading Verifying adequacy of rock bolting and other support
iv)	Tilt	Tilt meter	Monitoring tilting of buildings
v)	Load or stress in structural support	a) Load cell b) Pressure cell c) Strain gage	Verifying adequacy of structural support (rock bolts, ribs, liner plates, precast concrete liners, cross-lot bracing, tie-backs) Determining factor of safety on shoving stresses in soft ground shield tunnelling Increasing knowledge of support behaviour as input to improve design procedures
vi)	Groundwater level	Observation well/Standpipe piezometer	Monitoring draw-down of ground water table due to tunnelling or shaft. Measure rate of seepage from rock mass into tunnel
vii)	Pore water pressure	Piezometer	Forewarning of distress to buildings due to movement of soil or water towards soft ground tunnel or shaft
viii)	Vibration	Engineering seismograph	Verifying that ground and building vibrations due to blasting do not exceed an acceptable limit

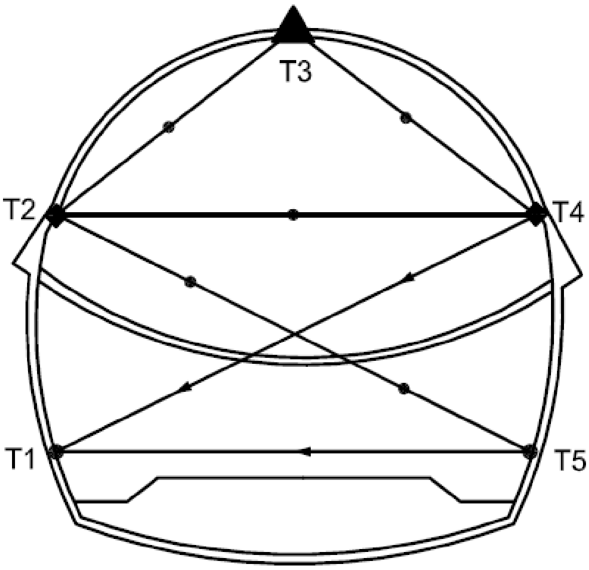

FIG. 2 ARRAY OF FIVE TARGET POINTS AT ONE LOCATION TO MEASURE TUNNEL CONVERGENCE

5.3 Instruments given in Table 1 shall be used as per the site conditions and as per the requirements in consultation with the designer.

6 TYPICAL TEST SECTION FOR MEASUREMENTS IN TUNNELS

6.1 Layout of an extensively instrumented zone is shown in Fig. 3. Measurements taken consist of following robust and valuable instruments:

a) Radial support pressure by pressure cells,

b) Load on support by load cells,

c) Depth of loosened rock mass by multi-point borehole extensometers, and

d) Rock closure and support deformation by tape extensometer or bi-reflex targets.

6.2 Strain in support can be measured by strain gauges. Instrumentation in the lined and concreted zone should consist of the following instruments which shall be embanded in concrete:

a) Stress meters, and

b) Strain meters.

6.3 Besides the above mentioned instrumentation, following data should also be collected which is required at the time of analysis of data:

a) *Geology* — mapping, fracture spacing and orientation, width of fracture zone, alteration and ground water.

b) *Rock mass quality (Q)*, *rock mass rating (RMR) and geological strength index (GSI)*

c) *Geophysical observations* — Seismic activity, *in-situ* stresses and their orientation, micro-seismic activity inside opening.

d) Time lag between excavation and installation of instrumentation shall be recorded along with a time record of further support installations or face advancements *vis-a-vis* observed deformations.

6.4 Significant researches have been done on the basis of field data from the instrumented tunnels in past. The tunnel instrumentation leads to collection of new field data, specially in complex geological conditions, and thus provides a great opportunity to learn the tunnel mechanics.

7 METHODS FOR PRESENTATION OF MONITORING DATA

7.1 Timely and continuous analysis of results and their interpretation can be used to verify the design assumptions and predicted system behaviour and ensure that the structural integrity fulfils safety, serviceability and economical requirements.

7.2 General Displacement Development Diagram

Redistribution of *in-situ* ground stress and resulting radial displacements initiate ahead of tunnel face which is yet to be excavated. Figure 4 depcits a typical radial displacement development diagram. Total displacements consists of displacement occurring ahead of the face (Z_{P0}), the displacement occurring between excavation and zero reading (Z_{P1}), and the monitored displacements after zero reading ($Z_m = Z_1$).

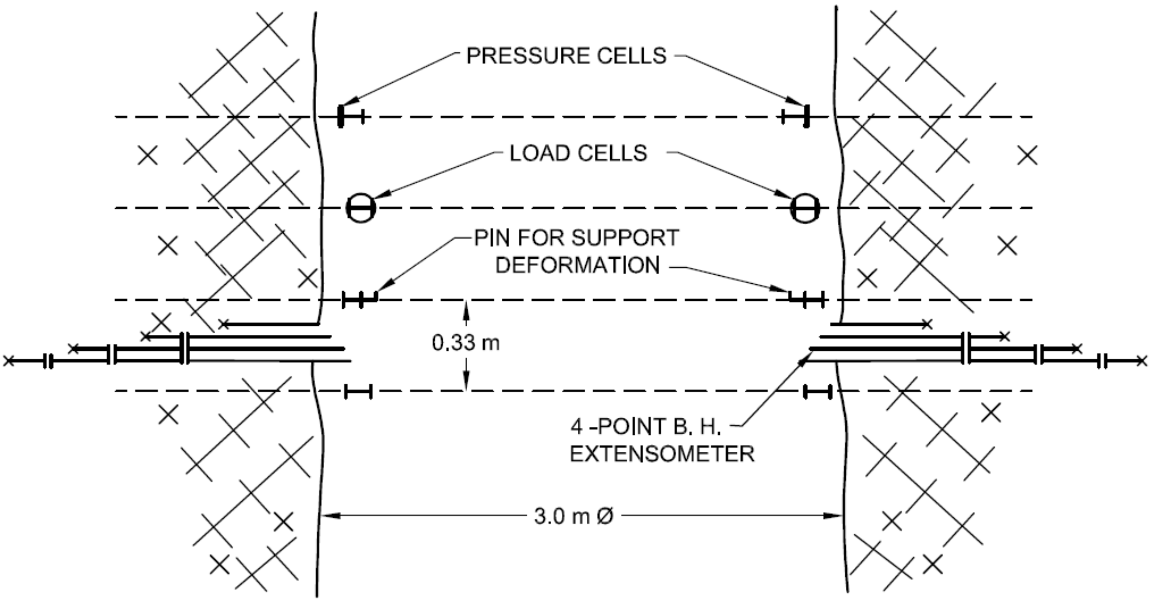

FIG. 3 LAYOUT PLAN OF A TYPICAL INSTRUMENTATION ZONE

7.3 3-D Displacement Diagrams

Assesssment of ground stabilization process can be visualized by plotting time-displacement or distance-displacment diagrams for displacement vectors for single/multiple points *vis-à-vis* various stages of excavation and support installations.

7.3.1 *Time-Displacement Diagram*

Displacement measurements of one or all targets in one monitoring cross-section are plotted in single diagram in relation to time. The displacement history is used to assess the stabilization process.

7.3.2 *Distance-Displacement Diagram*

Displacement measurements of one or all targets in one monitoring cross-section or same target location along different sections are plotted in single diagram in relation to the advance of face.

7.3.3 *Deflection and Trend Line Diagrams*

Deflection line diagrams represent the instantaneous longitudinal displacement profile (LDP) at one or more longitudinal section of the tunnel crown/wall at a given time. Several LDPs can be plotted for the same stretch of tunnel in single diagram. To eliminate variability in capturing zero reading, face displacement is considered zero and pre-displacement (between face and target installation) is produced by extrapolating the curve from previous three monitoring stations towards the zero displacement.

Trend lines are plotted on deflection line diagrams. These lines connect LDPs of various sections when face has advanced at fixed distance ahead of the longitudinal section. Each trend line relates to a distance value behind the face.

In homogenous ground conditions and un-interrupted cyclic construction sequences, deflection diagrams are obtained in the shape of an Onion-Shell and trend lines as straight lines.

Deflection and trend line diagrams are useful to predict approaching fault zones ahead of face or lack or work control in excavated portion of the tunnel.

8 MONITORING AND IMPLEMENTATION OF RESULTS

8.1 Monitoring plays a significant role in deciding the timely strengthening of primary supports otherwise with large deformations, in some cases, the roof and walls need to be trimmed to get the space for secondary lining. Large deformations may also create instability problems. Thus, it is important to have a good instrumentation programme and immediate implementation of instrumentation results to strengthen the primary supports.

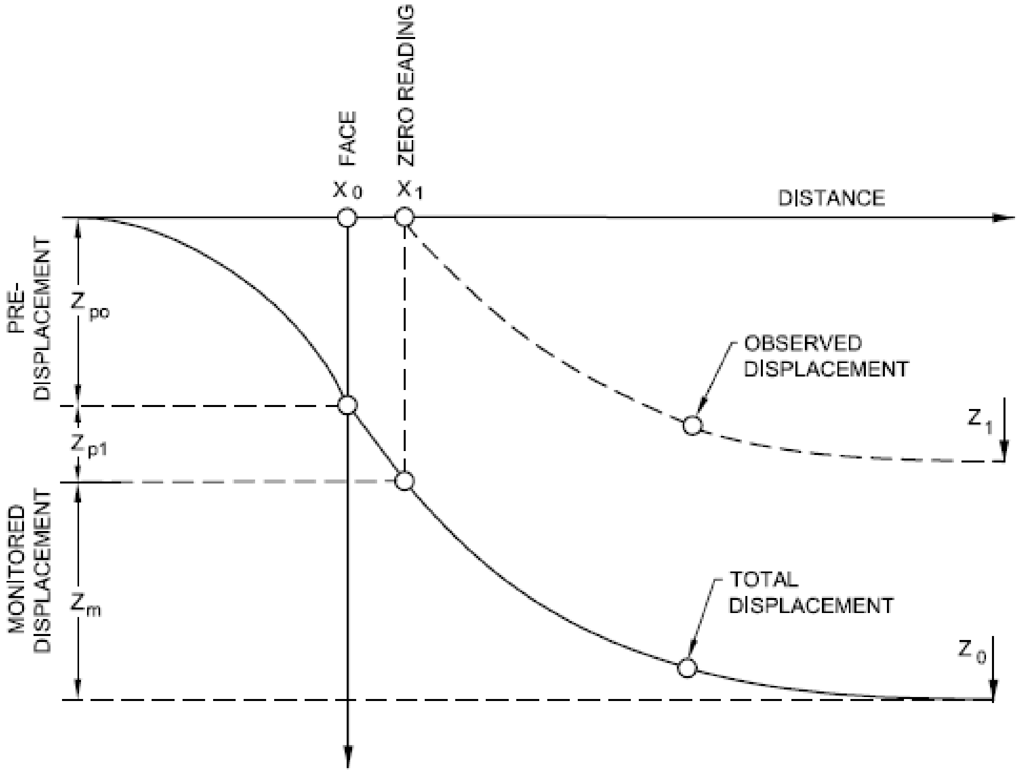

FIG 4 TYPICAL RADIAL DISPLACEMENT DEVELOPMENT DIAGRAM

8.2 A dual-level action plan for remedial measures is suggested as follows:

a) *Attention level* — It is a percentage of the predicted deformation. On exceeding this level/limit of convergence, the frequency of readings shall be increased in order to get the deformation speed. This trigger limit is set to study the deformation trends more closely and take countermeasures if the deformation remains continue with the same speed to the alarm limit. The attention level/limit, in general, is 70 percent of alarm level/limit.

b) *Alarm level* — It is the complete expected deformation from the design (coincides with the latest support section that will support the reached displacement and stress). Crossing of this limit will require initiating the procedure for actions and counter measures.

In a tunnel in India the convergence has crossed the alarm limit which called for the countermeasures in terms of longer rock bolts and additional shotcrete layer (*see* Fig. 5). After countermeasures, further monitoring shows that even the countermeasures were not adequate. Therefore, again additional supports were applied to make the tunnel stable. This example highlights the importance of observational method without tunnel failure.

9 PRECAUTIONS

The following precautions shall be observed:

a) Limits of deformation to be allowed shall be known and followed.

b) Some time, where high deformations are observed, the deformed roof and walls encroach the space available for secondary lining. Trimming the primary support and applying the secondary lining is not only costly and time consuming but also disturb the stabilized rock mass around the opening. Monitoring shall again be carried out to see if the ground is stabilized or not and then only the secondary lining support shall be applied.

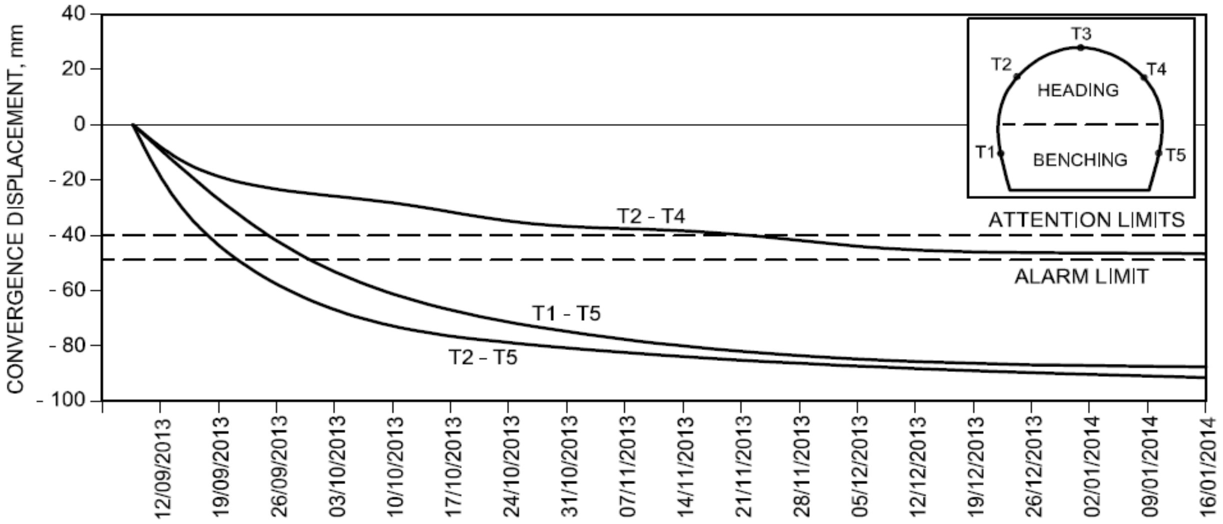

Fig. 5 Additional Rock Bolt and Shotcrete Support Installed after the Convergence Crossed the Designed Alarm Limit in a Tunnel [T1, T2, …, T5 = Bireflex Targets; T1-T5, T2-T4, T2-T5 = Convergence Between Respective Targets]

ANNEX A

(*Foreword*)

COMMITTEE COMPOSION

Rock Mechanics Sectional Committee, CED 48

Organization	*Representative(s)*
Indian Institute of Technology Roorkee, Roorkee	Dr N. K. Samadhiya (***Chairman***)
AIMIL Ltd, New Delhi	Shri Sharique Khan Shri Akhil Raj (*Alternate*)
Amberg Engineering AG, India, Gurugram	Shri Kripal Choudhary Shri Rakesh Pandita (*Alternate*)
Central Board of Irrigation and Power, New Delhi	Shri G. P. Patel Shri Uday Chander (*Alternate*)
Central Soil and Materials Research Station, New Delhi	Director Shri Hari Dev (*Alternate*)
Central Water and Power Research Station, Pune	Md Rizwan Ali Dr S. A. Burele (*Alternate*)
Central Water Commission, New Delhi	Member (D&R) Chief Engineer, Design (*Alternate*)
CSIR-Central Building Research Institute, Roorkee	Dr Shantanu Sarkar Shri Koushik Pandit (*Alternate*)
CSIR-Central Institute of Mining and Fuel Research, Dhanbad	Dr R. K. Goel Dr J. K. Mohnot (*Alternate*)
CSIR-Central Road Research Institute, New Delhi	Dr Pankaj Gupta Shri R. K. Panigarhi (*Alternate*)
Delhi Metro Rail Corporation, New Delhi	Representative
Directorate General Border Roads, New Delhi	Lt Col Parikshit Mehra Representative (*Alternate*)
Engineers India Ltd, New Delhi	Dr Altaf Uamani Shri Saikat Pal (*Alternate*)
Geological Survey of India, Kolkata	Shri M. Raju Shri Prasanta Mishra (*Alternate*)
Hindustan Construction Company Ltd, Mumbai	Shri Satish Kumar Sharma Dr Mahesh Chaudhary (*Alternate*)
Indian Institute of Technology, Roorkee	Dr Mahendra Singh Dr Priti Maheshwari (*Alternate*)
Indian Institute of Technology, New Delhi	Representative
Indian Institute of Technology, Dhanbad	Representative
Indian Society for Rock Mechanics and Tunnelling Technology, New Delhi	Representative
Irrigation Research Institute, Roorkee	Shri Tribhuvan Singh Shri Naveen Singhal (*Alternate*)
Konkan Railway Corporation Ltd, Navi Mumbai	Shri Rajesh Agarwal Shri L. Prakash (*Alternate*)
National Diasater Management Authority, New Delhi	Shri J. S. (Mitigation) Dr Ravinder Singh (*Alternate*)

Organization	*Representative(s)*
National Highways & Infrastructure Development Corporation Limited, Delhi	Representative
National Highways Authority of India, New Delhi	Representative
National Hydroelectric Power Corporation Ltd, Faridabad	Shri N. K. Mathur Shri Imran Sayeed (*Alternate*)
National Institute of Roack Machanics, Bengaluru	Shri A. Rajan Babu Shri G. Gopinath (*Alternate*)
National Thermal Power Corporation Ltd, New Delhi	Shri N. K. Jain Shri Prakash Rawat (*Alternate*)
Rail Vikas Nigam Ltd, New Delhi	Shri Sumit Jain Shri Vijay Dangwal (*Alternate*)
RITES Ltd, Gurugram	Shri Pallab Pal Dr B. R. Singh (*Alternate*)
THDC India Limited, Rishikesh	Shri T. S. Routela Shri Smrat Mukherjee (*Alternate*)
In personal capacity (*C-1004, Park View City-2, Sector-49, Gurugram*)	Dr Manoj Verman
In personal capacity (*A-125, Prodhyogiki Apartment, Sector-3, Dwarka, New Delhi*)	Dr Rajbal Singh
BIS Directorate General	Shri Sanjay Pant, Scientist 'F' and Head (Civil Engineering) [Representating Director General (*Ex-officio*)]

Member Secretary

Dr Manoj Kumar Rajak
Scientist 'D' (Civil Engineering), BIS

(*Continued from second cover*)

NOTES

1 Although some elastic deformations are lost in tunnel instrumentation, yet the time-dependent deformations are important and measured by quick tunnel instrumentation. It should be kept in mind that in the highly squeezing ground conditions the tunnel closure may continue for longer duration, if adequate measures are not taken. Time-dependent behaviour is generally not considered in computer-aided designs)

2 Adequate number of instruments should be used as their survival rate is very low in tunnels in the weak rocks.

Observations and measurements of the ground behaviour are needed in almost all tunnel projects. In principle, difficulties in predicting the geotechnical behaviour for underground excavations can mainly be found in the variation in rock mass quality, the interaction between the rock mass and support, and in the quality of the executed support measures.

Considering all these aspects relating to the need and importance of observational methods and decisions and precautions required to be taken in that context, this new standard has been formulated, and covers basic considerations and requirements, data requirements, role of instrumentation for tunnelling, important measurements, typical test section for measurements in tunnels, methods for presentation of monitoring data, and monitoring and implementation of results.

The composition of the Committee responsible for the formulation of this standard is given in Annex A.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 ‘Rule for rounding off numerical values (*revised*)’. The number of significant places retained in the rounded off value should be same as that of the specified value in this standard.

Bureau of Indian Standards

BIS is a statutory institution established under the *Bureau of Indian Standards Act*, 2016 to promote harmonious development of the activities of standardization, marking and quality certification of goods and attending to connected matters in the country.

Copyright

BIS has the copyright of all its publications. No part of these publications may be reproduced in any form without the prior permission in writing of BIS. This does not preclude the free use, in the course of implementing the standard, of necessary details, such as symbols and sizes, type or grade designations. Enquiries relating to copyright be addressed to the Director (Publications), BIS.

Review of Indian Standards

Amendments are issued to standards as the need arises on the basis of comments. Standards are also reviewed periodically; a standard along with amendments is reaffirmed when such review indicates that no changes are needed; if the review indicates that changes are needed, it is taken up for revision. Users of Indian Standards should ascertain that they are in possession of the latest amendments or edition by referring to the latest issue of ‘BIS Catalogue’ and ‘Standards: Monthly Additions’.

This Indian Standard has been developed from Doc No.: CED 48 (14889).

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002
Telephones: 2323 0131, 2323 3375, 2323 9402 *Website*: www.bis.gov.in

Regional Offices:

		Telephones
Central	: Manak Bhavan, 9 Bahadur Shah Zafar Marg NEW DELHI 110002	2323 7617 2323 3841
Eastern	: 1/14 C.I.T. Scheme VII M, V.I.P. Road, Kankurgachi KOLKATA 700054	2337 8499, 2337 8561 2337 8626, 2337 9120
Northern	: Plot No. 4-A, Sector 27-B, Madhya Marg CHANDIGARH 160019	265 0206 265 0290
Southern	: C.I.T. Campus, IV Cross Road, CHENNAI 600113	2254 1216, 2254 1442 2254 2519, 2254 2315
Western	: Manakalaya, E9 MIDC, Marol, Andheri (East) MUMBAI 400093	2832 9295, 2832 7858 2832 7891, 2832 7892

Branches : AHMEDABAD. BENGALURU. BHOPAL. BHUBANESHWAR. COIMBATORE. DEHRADUN. DURGAPUR. FARIDABAD. GHAZIABAD. GUWAHATI. HYDERABAD. JAIPUR. JAMMU. JAMSHEDPUR. KOCHI. LUCKNOW. NAGPUR. PARWANOO. PATNA. PUNE. RAIPUR. RAJKOT. VISAKHAPATNAM.

Published by BIS, New Delhi